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**High Performance Morphological Filtering of Cirrus
Emission from Infrared
Images**

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(Note: The overall PI Dr. Jeff Pedelty submitted an earlier version of this report 1 year ago where it has been available on a public web site (see below). This report is slightly updated to include more recent publications and the final few months of activity on the grant.)

Project Overview

The project was designed to explore new morphological filtering techniques for the removal of foreground Galactic "Cirrus" emission from NASA Infrared Astronomical Satellite (IRAS) data, especially at 100 microns, using parallel processors as the main engine for achieving this result. The ultimate aim was to provide NASA with completely filtered data by the end of the grant period for the entire IRAS 100 and possibly 60 micron database. If successful, the filtered data would reveal many new sources of IR emission, especially at low galactic latitudes, which had previously been heavily confused with diffuse Galactic "cirrus".

Introduction

This comprises the ISU version of the final report of the Guest Computational Investigator research funded by the NASA Earth and Space Sciences Applications Project (ESS), part of the federal High Performance Computing and Communications (HPCC) program. Much of the material in this report (but not all) can be found on our web site situated at Goddard in the following ULR

<http://odyssey.gsfc.nasa.gov/~pedelty/gci.html>

Unlike the hardcopy shown here, the web version allows full access to the software discussed in this document and many other useful links to papers etc.

and characterization of the language and data layout considerations on the MasPar was submitted to the Frontiers '95 conference (Pedelty, 1995, "A Comparison of MasPar Implementations of Morphological Image Processing"). A PVM implementation was also presented to a computing conference (Pedelty and Thorp, 1994, "A PVM Implementation of Mathematical Morphology")

This high performance MasPar implementation of the morphological operations enabled the quick turnaround necessary to generate a refined morphological filter. This refinement constituted a major portion of the project, and comprised a significant portion of the Ph.D. thesis of Mr. Lunxiong He in the Department of Electrical and Computer Engineering at the Iowa State University. This thesis was successfully defended on May 31, 1996.

From the initial morphological filtering studies, it was known that in the area of very bright galactic cirrus, or bright galaxies, the method of filtering tended to oversubtract flux from the maps, leaving negative residuals behind. In addition, little was known about the flux-conserving nature of the morphology algorithm. Finally, it was necessary to determine how to classify the galactic cirrus efficiently, and whether the characteristics of Galactic cirrus were sufficiently uniform to allow a "universal" filter to be created. It was also not known whether it was possible to create a filter for the 60 micron IRAS images.

This refinement and extension process was successful, and led to the publication of a more rigorous paper on the method (He, Basart, Appleton, and Pedelty, 1995, "A Self-consistent Mathematical Morphological Filter for Removing "Cirrus" Noise from Far-Infrared of simulated sources placed into very heavily "cirrus" contaminated fields could be conserved to within a few percent. For the 100 micron dataset, this seemed to be a major advance over previously published results, especially near the galactic plane.

A second major advance in the project was the development of an automatic method for classifying "cirrus". The new method seemed very superior to the "hand-on" method previously used, and apparently was capable of working well in many different IRAS fields.

One of the big surprises was the realization that the morphological filter could work extremely well within a few degrees of the galactic plane, and interesting new sources were detected close to the plane. These ranged from new large-scale dust features, possibly associated with old supernova remnants, to many previously un-cataloged point sources. We therefore began an optical R-band survey of many of these new sources to follow-up on the IRAS detections. We discovered that many of the new sources are galactic in origin, although many background galaxies have been identified. No unidentified galaxies have yet been found, but the optical survey (being conducted by Dr. Appleton at the ISU Fick Observatory) is still in progress. Sources fall into 3 main categories. Large-scale dust structures which have a bubble-like appearance, smaller scale linear dust structures which are rather different from the diffuse cirrus, and finally

L. X. He, P. N. Appleton, and J. P. Basart, "Improvements in filter design for removing galactic 'cirrus' from IRAS image, "Proc. of the 4th Annual Midwest Electro-Technology Conference, pp. 27-30, ISU., Ames, IA, (1995)

J. P. Basart, L. X. He, P. N. Appleton and J. A. Pedelty, "Improvement in filter design for removing galactic 'cirrus' emission from IRAS images," Astronomical Data Analysis Software and Systems IV, R.A. Shaw, H.E. Payne, and J.J.E., Hayes, eds, pp. 289-294 (1995)

L. X. He, Ph. D. Thesis, "Pattern recognition and Image Processing of Infrared Astronomical Satellite Images", Iowa State University, Ames, Iowa. *** (Successfully defended July 1996).****

L. X. He, P. N. Appleton, J. P. Basart & J. A. Pedelty, "An Advanced Morphological Filter for Long Wavelength IRAS Survey Fields", AJ, (In Preparation, (1998) ***Work still in progress Dec 1997-preprint soon available***

L. X. He, J. P. Basart, P. N. Appleton & J. Pedelty, " A Self-consistent Mathematical Morphological Filter for Removing "Cirrus" Noise from far-IR Astronomical Images, in "Neural, Morphological, and Stochastic Methods in Image and Signal processing, E. R. Dougherty, F. Preteux & S. S. Shen, Proc. SPIE, 2568, pp104-116 (1996) **Major Article describing the details of the new filter***

L. X. He, P. N. Appleton, J. P. Basart and J. A. Pedelty, "A CD-ROM Imaging Database of the 60 and 100 Micron IRAS Sky Free of Average Cirrus Emission", (In Preparation. Will include 3 CD ROMs containing * images of filtered sky. Available January (1998). ***CD ROM is being written now-December 1997*****

Publications and Presentations

P. N. Appleton, P. R. Siqueira and J. P. Basart, "A Morphological Filter for Removing 'Cirrus-like' Emission from Far-IR Extragalactic IRAS Fields" *Astron. J.* 106, 1664- 1678 (1993) ***major research article***

J. A. Pedelty, P. N. Appleton, V. Charmandaris and J. P. Basart, "Morphological Filtering of Infrared Cirrus Emission on Parallel and Distributed Computers", *B.A.A.S.*, 25, 805 (1993).

J. Pedelty and J. Thorp, "A PVM Implementation of Mathematical Morphology," in *Concurrent Computing in the Physical Sciences*, ed. D. Browne, and R. Kalia (World Scientific, New York). (1993).

J. Pedelty and T. El-Ghazawi, "Mapping Morphological Filters onto High Performance Architectures," presentation to Supercomputing '93, Portland, OR. (1993)

L. X. He, P. N. Appleton, J. P. Basart, J. A. Pedelty, "A Self-consistent Design Approach to the Removal of Galactic Cirrus Emission from IRAS Images", *BAAS.*, 184, 650 (1994)

J.A. Pedelty, "A Comparison of MasPar Implementations of Morphological Filtering," submitted to the *Frontiers of Massively Parallel Computation* conference (1994).

L.X. He, P. N. Appleton, and J. P. Basart, "Designing morphological filters for removing 'cirrus' emission from far-IR extragalactic fields," *Proc. of the 3rd Annual Midwest Electro-Technology Conference*, pp. 43-46, ISU., Ames, IA (1994)

J. A. Pedelty, P. N. Appleton, and J. P. Basart, "Morphological filtering of infrared 'cirrus' emission using the MasPar," *Astronomical Data Analysis Software and Systems III*, D.R. Crabtree, R.J. Hanisch, and J. Barnes, eds., pp. 308-311 (1994)

L. X. He, J. P. Basart, P. N. Appleton, & J. A. Pedelty, , "A Self-consistent Mathematical Morphological Filter for Removing "Cirrus" Noise from Far-Infrared Astronomical Images", *SPIE Conference Proc.*, 2568, (S.S. Shen, E. R. Dougherty, F. Preteux, eds.), pp. 104-116, (1995) (REFEREED ABSTRACT)

J. A. Pedelty, P. N. Appleton, J. P. Basart, L. X. He, "Morphological Image Processing on Parallel and Distributed Computers," presented to the *Astronomical Data Analysis Software and Systems* conference, Baltimore, MD, September, 1994. (INVITED TALK)

is a presentation made to the 4th ADASS conference in Baltimore, MD in September, 1994.

A much more detailed paper describing these MasPar implementations was submitted to the Frontiers '95 conference. Although the paper was not accepted, the text is available. (see Web site).

Availability

The package can be retrieved from our web site:

<http://odyssey.gsfc.nasa.gov/~pedelty/gci.html>

Students Involved in Project

Dr. Lunxiong He

Dr. Lunxiong He passed his final oral examination for the Ph.D. in Electrical and Computer Engineering from the Iowa State University on May 31, 1996. His Ph. D Thesis (entitled "Pattern recognition and Image Processing of Infrared Astronomical Satellite Images", was funded largely by this project and the grant played a central role in his research which was devoted to developing a new version of the fmorphological filter.

H. C. Hsieh

Mr. H.C. Hsieh worked in the spring of 1996 to make final production images for the CDROM filtered dataset. These images, along with a fully explanation of how to use the CDROM will be included with some other useful software on the CD ROM. Along with each filtered image, which corresponds to a 100 micron IRAS image from Volume II of the IRAS SKY SURVEY ATLAS, there is a classification image which shows how the filnal filter decided on which part of the image was "cirrus" and which contained interesting data. The CDROM is going into production at the time of writing (Dec 1997) and will be shipped to NASA early in January 1998. (Contact P. N. Appleton, Iowa State University for details).

compact sources of a variety of different origins. It is the latter type that is the subject of the optical follow-up and will yield some very interesting results.

At the time of writing (Dec 1997) we have completed the filtering of the IRAS database at 100 microns using mathematical morphology. Earlier attempts to filter the 60 micron images were less successful and will not be included in the final CDROM. The filtered images along with the original IRAS survey fields and are (currently-Dec 1997) be written to CD ROMs in preparation for release to NASA in Jan 1998. We have also made detailed comparisons between the morphological mapping approach and several other well known filtering approaches. For example, Fourier filtering and wavelet analysis have both been explored as alternative methods to morphology (See L. He's Thesis). We have found that, during these tests, the morphological approach was in general preferable to the other techniques. These comparisons will be discussed in a paper on the topic. We also plan to publish a catalog of IRAS sources in the Galactic plane which will complement other catalogs. However, this component will take a few years to complete since it requires follow-up optical observations which are currently underway outside the scope of this project.

Contributed Software

MasPar Routines for Grayscale Mathematical Morphology

Overview

This package (available on our web site) contains routines to perform some of the basic operations of grayscale mathematical morphology, also known as morphological image processing. The functions 'dilate' and 'erode' are currently available, from which the 'opening' and 'closing' operations can be performed. The routines run on the MasPar MP-1 and MP-2. Arbitrarily sized structuring elements are supported. A driver program is included as a demonstration of how to use these routines.

Two different sets of routines are provided: one is written in MasPar Fortran (MPF) and the other is written using the MasPar Language (MPL). In addition, an implementation in Fortran 77 is included for comparison purposes. The MPL implementation is about 15% faster than the MPF. However, the MPF routines are more flexible in that they can be used on any size images and on a MasPar with any number of processors. The MPL routines will require some additional development to work on other than 512x512 images on a 16K processor MasPar. In addition, the MPF main program will directly read and write images in FITS format, the standard in astronomy. Adapting to binary or other raster formats would be straightforward. The main program in the MPL implementation can read the binary image data directly from the MasPar Parallel Disk Array (PDA). Test images are provided to exercise each implementation.

A paper briefly describing these MasPar implementations is available. It was contributed to the conference proceedings of the 3rd Annual Astronomical Data Analysis Software and Systems conference held in Victoria, B.C., Canada in October, 1993. Also available

Unlike the web version, this version has been updated to include information about the final production of the CDROM and is more complete regarding publications (as of dec 1997). The web site will, very shortly be updated to reflect these changes.

Goddard Investigator (Overall PI of project)

Dr. Jeffrey Pedelty, Biospheric Sciences Branch, NASA Goddard Space Flight Center

ISU Investigators

Dr. Philip Appleton, (PI of the ISU Component), Department of Physics and Astronomy, Iowa State University

Dr. John Basart, Department of Electrical and Computer Engineering, Iowa State University

Lun He, (Ph. D Student- now Dr. He) Department of Electrical and Computer Engineering, Iowa State University

Summary of Accomplishments

This project sought to extend and improve upon the initial morphological filtering results generated for the very obscured M81/M82 galaxy group field. Among the first accomplishments of the HPCC funding was the peer-reviewed publication which described these results (Appleton, Siqueira, and Basart, 1993, "A Morphological Filter for Removing 'Cirrus-like' Emission from Far-IR Extragalactic IRAS Fields" Astron. J. 106, 1664-1678).

However, some problems with the filter remained to be solved before the method could be applied to the IRAS database as a whole. This further required that the processing time required for the basic morphological operations be dramatically reduced. The initial experiments required several hours on a workstation to generate a new result, and this turnaround time severely hampered further testing.

To this end we implemented the basic morphological image processing operations on the MasPar parallel computers at both the Goddard Space Flight Center and the Scalable Computing Lab of the DOE Ames Laboratory at Iowa State University. We focused on the MasPar implementation given the availability of MasPar's at each institution, but versions for most of the major platforms were created. The final MasPar MP-2 implementation reduced the filtering time to less than 10 seconds.

Overviews of the MasPar and other implementations were presented to a number of astronomical conferences (see publications section). A much more detailed description